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by

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ON THE PECULIARITIES OF THE LONGITUDINAL DISTRIBUTION OF SOLAR ACTIVITY

by Yu. I. Vitinskiy

SUMMARY

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A method of isolines in application to the drawing of synoptical solar maps for one cycle is given. It is shown that this method can be applied with success for recognizing the active regions on the sun. The peculiarities of the longitudinal distribution of various indices of solar activity are considered. The presence of active longitudes for which the Fay law is practically absent (in agreement with Losh and Waldneier) is confirmed. It is noted that the main population of active longitudes are recurrent groups. The distribution of the decay function with longitude is considered. It is shown that this distribution differs from that for the sum of daily spottedness for a cycle, indicating that decay and outburst processes belong to different depths. It was found that the magnetic strength index of spots is unsuitable for the study of longitudinal distribution as much selection is involved when procuring data on this index. In conclusion the peculiarities of recurrent groups populating active solar longitudes are discussed.

The problem of whether the latitudinal and longitudinal distribution of solar activity is uniform or non-uniform in one or both directions has long attracted the attention of numerous researchers. This problem usually consisted of two parts. One of them eventually developed into the Sperer law of the latitudinal creep of the spot-formation zone in the course of a cycle, and the other usually figures in literature in connection with the active solar longitudes. But the problem of the longitudinal and latitudinal distribution of solar activity has not yet been solved. This has been due largely to the methods still used by the researchers.

The initial material for this problem are the synoptic maps of the Sun. There are two such maps in existence now: daily and per revolution. The daily maps of the Sun do not have a system of longitudes rigidly fastened to the Sun, and cannot therefore be used for our purpose. Such maps are

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more suitable for the study of heliogeophysical bonds. As for the synoptic maps of the Sun, per revolution, they are characterized by the following features.

1. They show the various solar formations only in the day they pass the central Solar meridian, and in this sense they can be considered only from the point of view of the terrestrial observer, without going into the dynamics of these formations.

2. They show only the visible solar formations (this is explained by the fact that this is the only type of solar activity actually observable at present). It is therefore impossible to get a particular indicator of solar activity for every point of the solar surface.

3. They prevent the compilation of composite synoptic maps of the Sun even for several revolutions, in view of the first two peculiarities, inasmuch as the picture becomes very confused.

Thus it can be said that the synoptic maps of the sun compiled heretofore have been of the Lagrange type, as they actually dealt with the behavior of an individual solar formation from the point of view of an observer moving along with it on the solar surface as it were.

It is quite natural that the use of such synoptic maps of the Sun involved a considerable amount of arbitrary judgment in the recognition of the active centers, particularly their boundaries. Attempts were made to eliminate this arbitrary feature by the introduction of various statistical criteria. But these investigations, though based on the same materials, frequently led different authors to diametrically opposite conclusions.

All this compelled us to try another method of compiling a synoptic map of the Sun based on the Euler principle. It was actually a method of isolines usually applied in meteorology.

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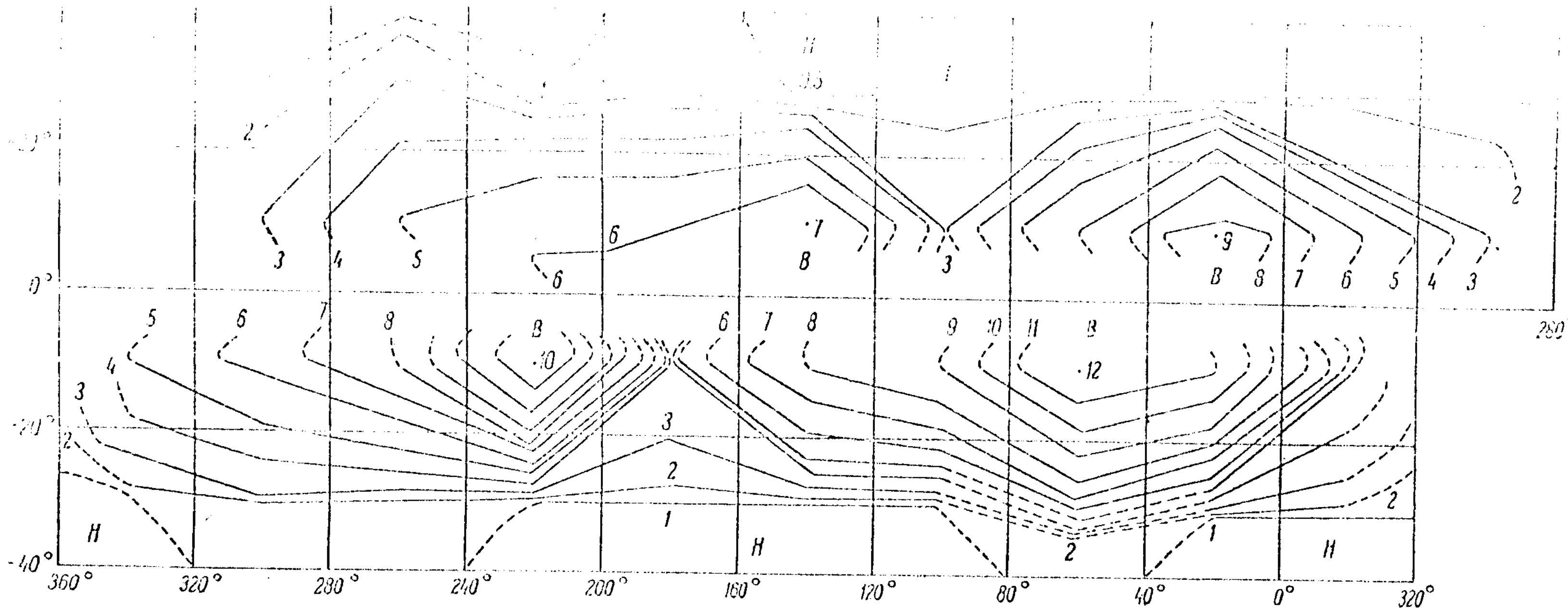

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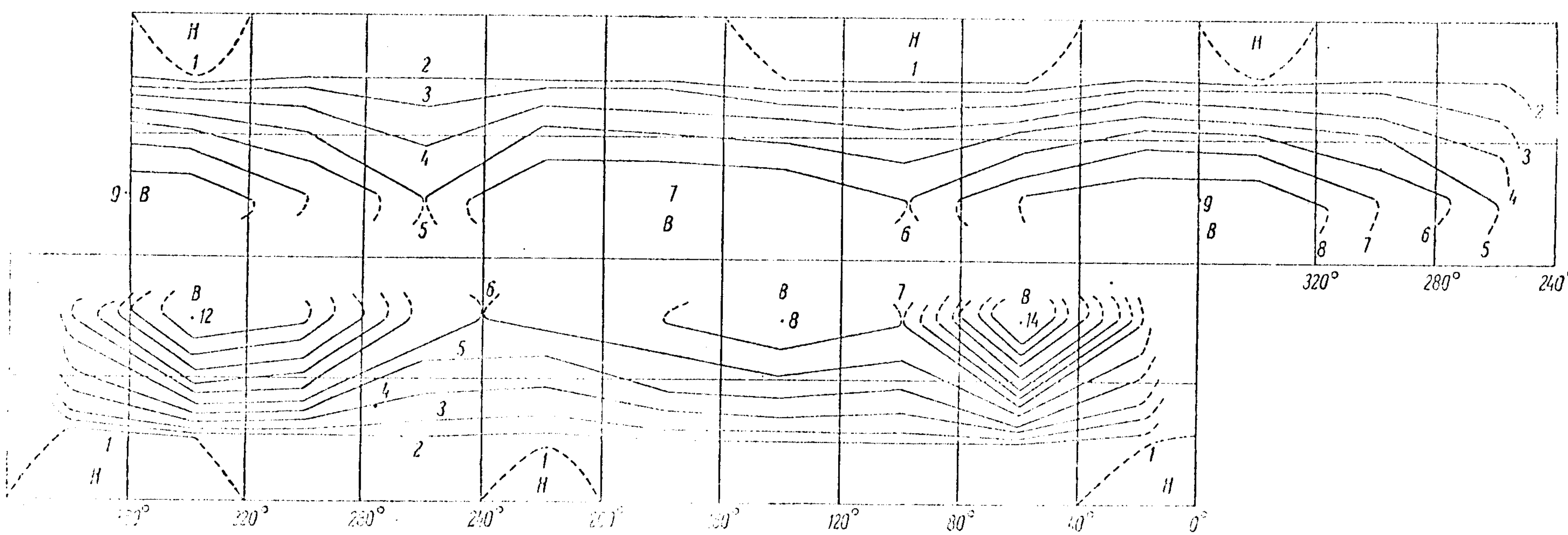

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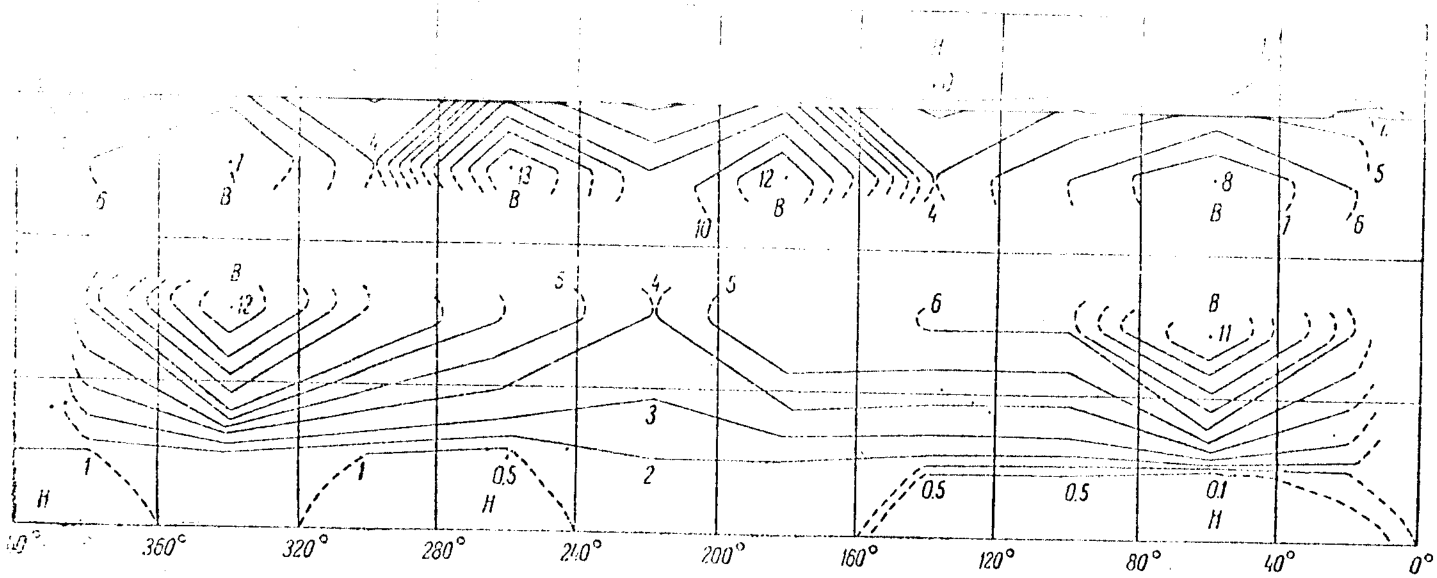

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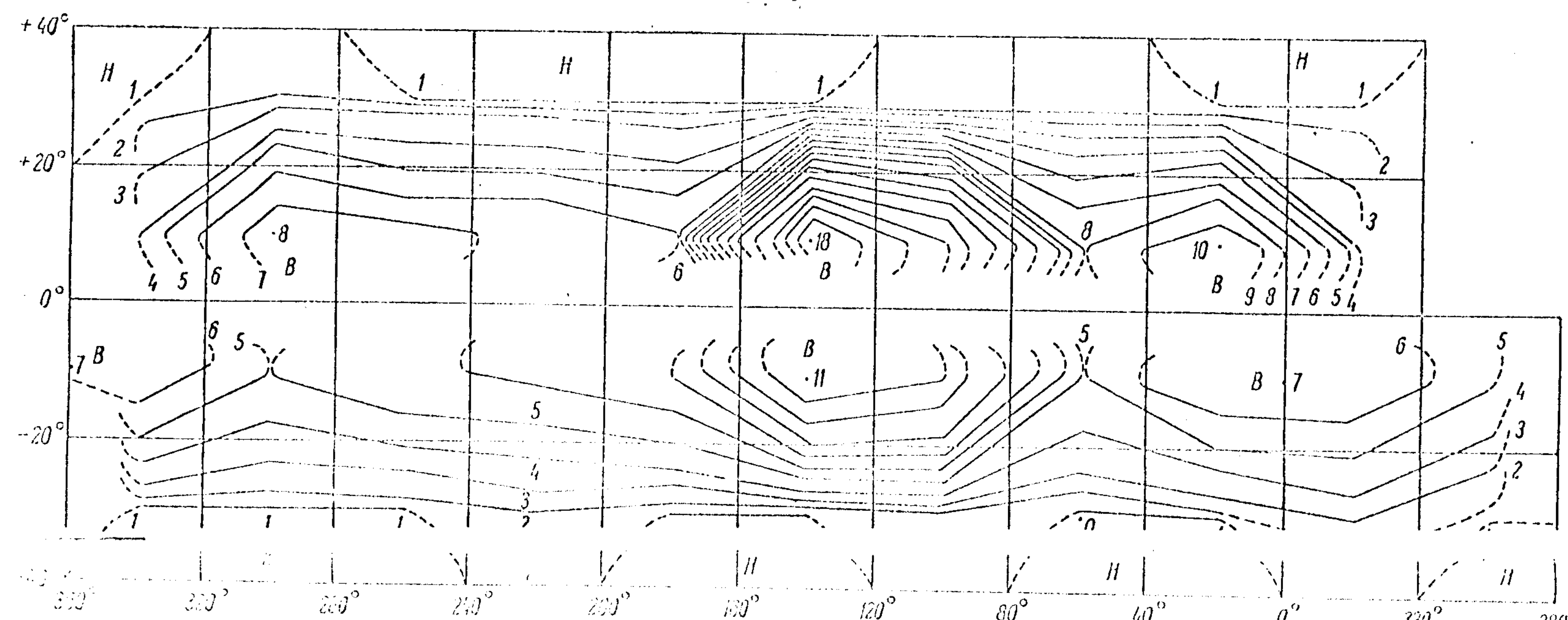

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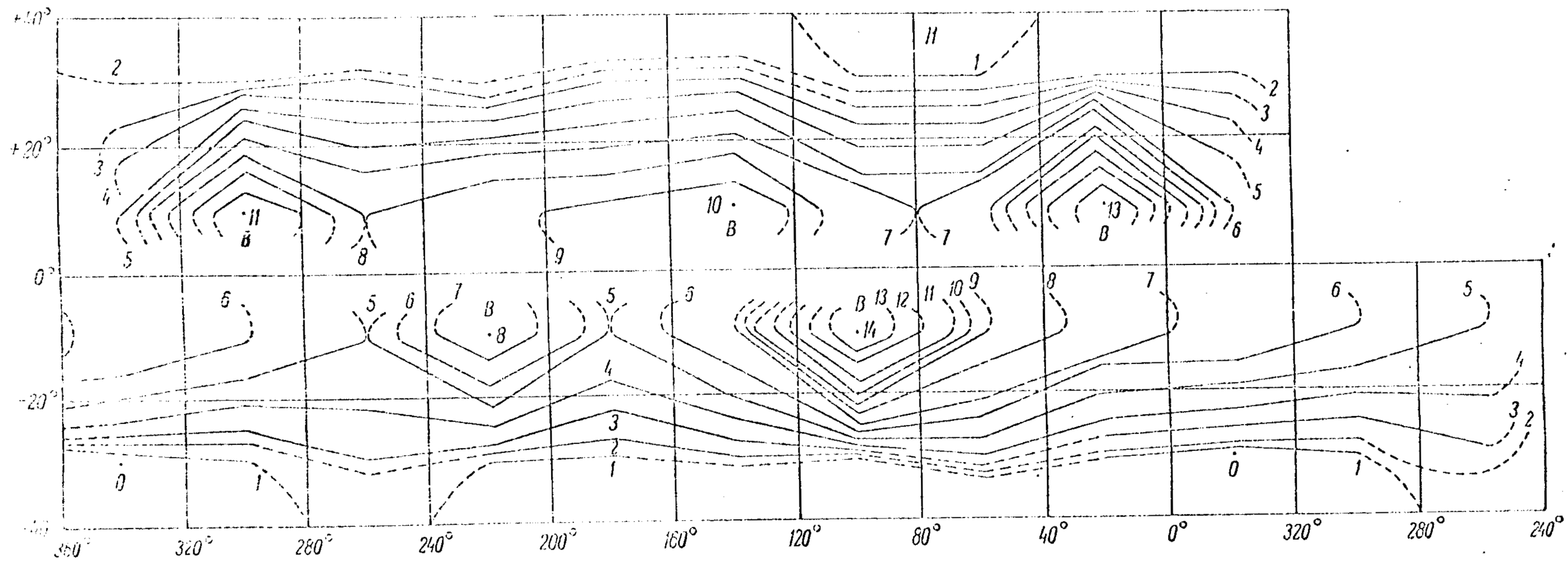

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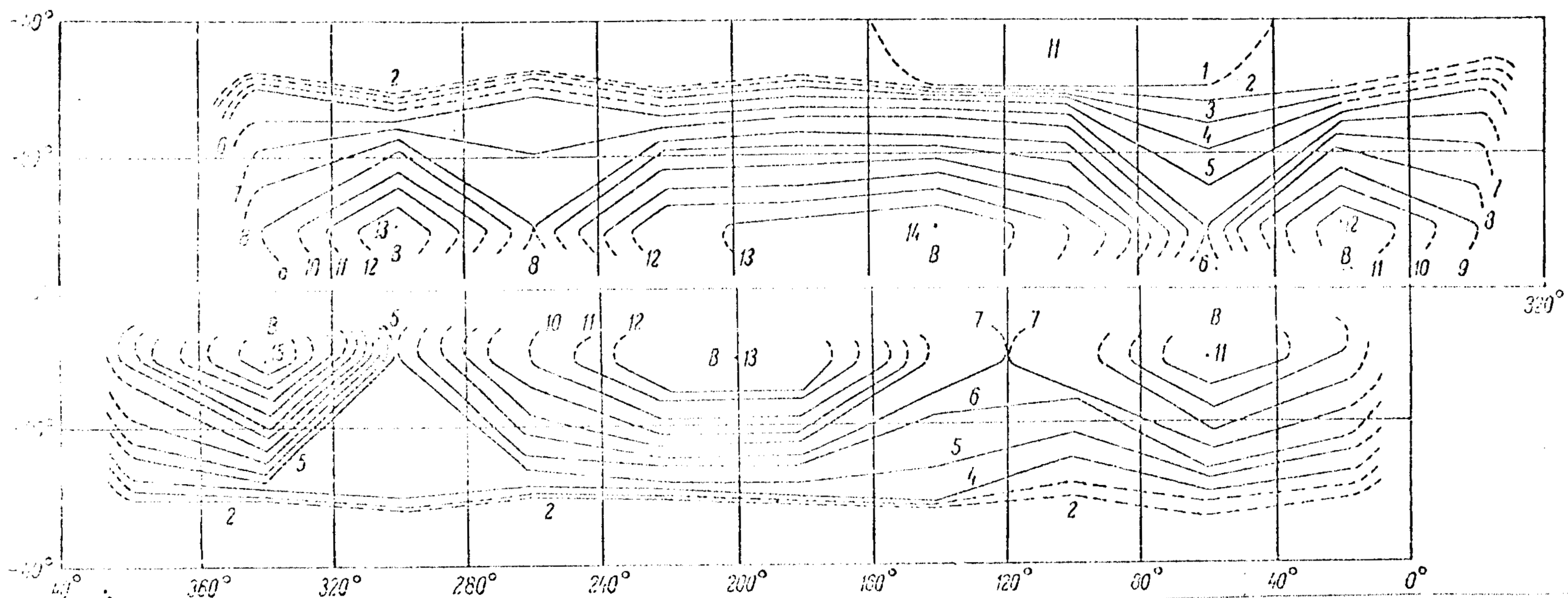

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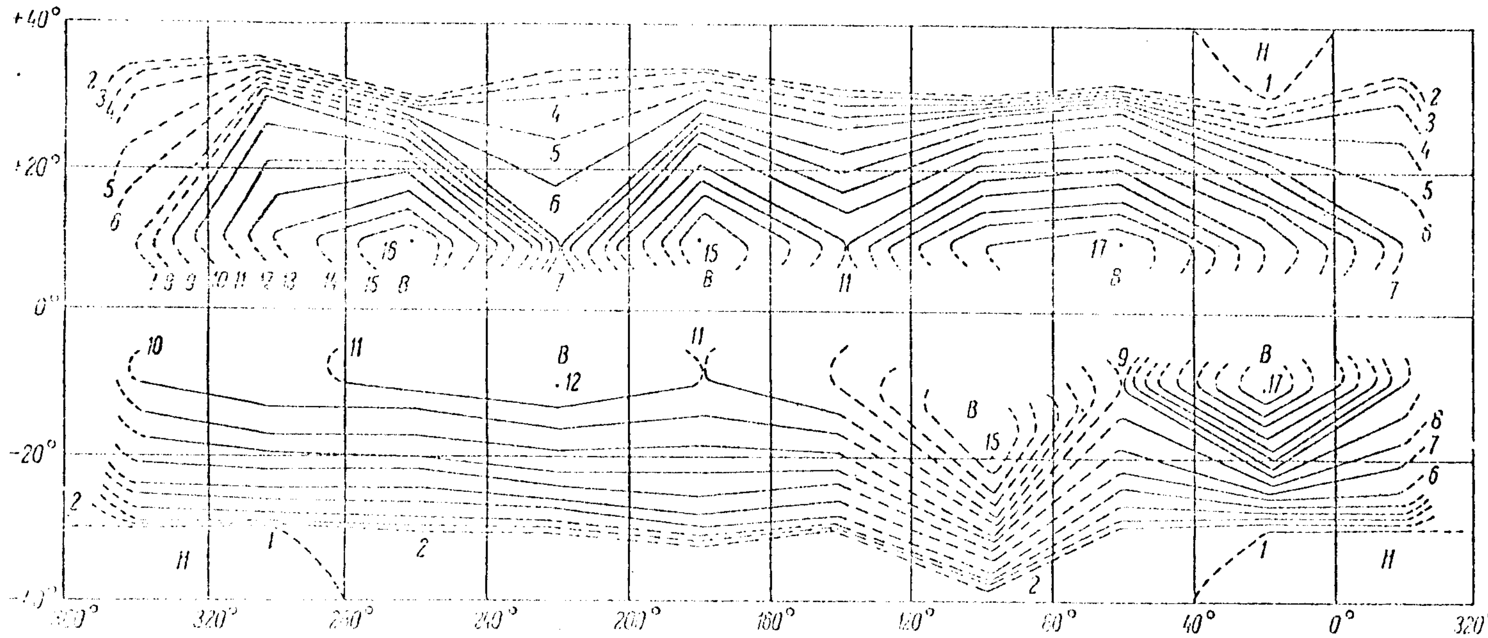


Fig. 1

Let us take a certain number of rigidly fixed points on the solar surface and consider some kind of indicator of solar activity in each of those points. We will assume that a given index applies to a scalar continuous field with a terminal number of points of discontinuity. We can then obtain the field distribution of that index in the form of a system of isolines.

But the use of this method, which we shall call the isoline method, produces three difficulties in the case of the Sun.

1. There are practically no indexes of solar activity at present that would produce a continuous field. A possible exception are the magnetic fields of the sun spots. But, as we will show later, that index can hardly be used to good effect at present.

2. In the case of long time intervals, the effect of Sperer law may produce certain distortions in the separation of the active centers (by latitude).

3. The manifestation of the Fay law of differential rotation at long time intervals may result in the distortion of the longitudinal distribution of any indicator of solar activity.

As for the second and third difficulties, the question of their significance can be decided only a posteriori. The first difficulty can be avoided in the same way as is done in the compilation of isoneph maps in meteorology where probability takes the place of a definite index.

Before applying the isoline method we had to solve the problems of the time interval, the number of points on the solar surface and the index of solar activity.

We will take the length of a solar activity cycle as a time interval. Our time interval will thus not be constant. But what is important here is that it be characterized by a very definite and completed process.

The selection of the number of points on the solar surface is, in effect, equivalent to the selection of the dimensions of the active regions on the Sun. It is a known fact that the dimensions of the largest groups of sun spots are 20° latitude and 40° longitude [1]. We have therefore decided to divide the solar surface into areas of such sizes, which means 36 points placed in the center of each such area of the spot-formation zone.

In the first stage we will use the average daily spottedness of each area in each revolution (S_i) as an index of solar activity. In this case the spottedness is considered in terms of area. This index is defined as the sum of the daily values of the spot group areas located within a given area and divided by 14, which is the maximum number of days the groups have existed on the visible hemisphere of the sun. Naturally, we must also assume that the picture on the invisible solar hemisphere is about the same as on the visible one. We get the sum S_i for each area per cycle. We will thus deal with magnitudes which appear to be proportional to the energy of solar activity released in the course of a cycle in a given area of the solar surface.

We have used the isoline method to compile a synoptic map of the Sun representing cycles 12-18. The data on the sun spots were taken from the Greenwich photoheliographic catalogs for cycles 12-16, and from the Pulkovo catalogs of solar activity for cycles 17-18. Fig. 1 shows such maps for index S_i of cycles 12-18. In this case, Kerrington longitudes are measured off on the X-axis and heliographic latitudes on the Y-axis.

An examination of these maps shows that the isoline method facilitates a clear recognition of the active centers on the Sun. We should point out

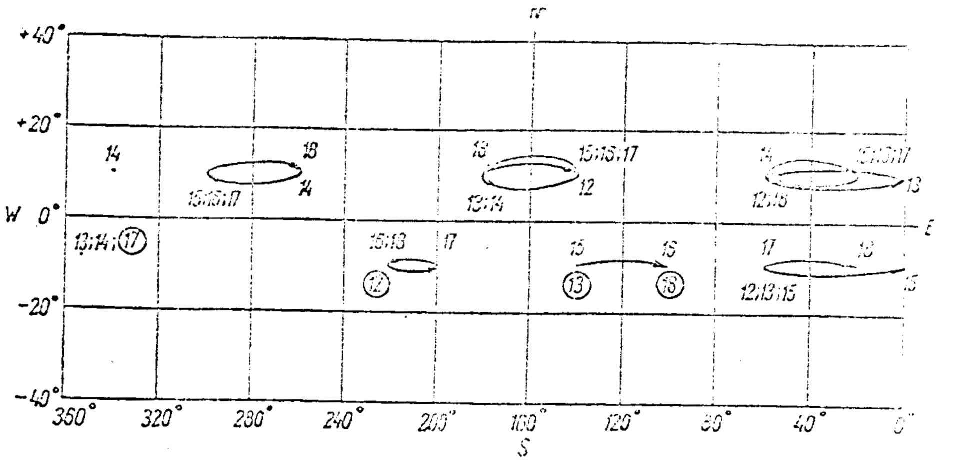


Fig. 2.

here that the problem at hand is not the distribution of some manifestation of solar activity but the distribution of the cause of solar activity in the photosphere expressed by $\sum S_i$. Inasmuch as the cycle we selected is large enough in latitude, the effect of the Sperer law of the spot-formation zone creep has practically not been felt. At the same time, such a scale makes it possible to find only the longitudinal distribution of a given index of solar activity. We will therefore examine this problem first. As for the latitudinal distribution of solar activity, it can be recognized only when the latitudinal dimensions of the areas is reduced to 10°.

The most conspicuous feature of a synoptic chart of the sun (see Fig. 1) is that the active centers remain in practically the same longitudinal intervals for 2-3 cycles. Moreover, if there are any deviations from these longitudinal intervals, they do not exceed 40°, that is the scale of the longitudinal area, and have no definite, systematic direction. Here we are approaching the problem of the active longitudes of the Sun.

The problem of the existence of active longitudes has so far been solved by statistical methods alone [2]. After a recent examination of

Greenwich materials for a period of 63 years, U. Becker [3] came to the conclusion that there were not actual active longitudes on the Sun. This conclusion was based on the use of a certain statistical method and postulate which should be discussed at some detail.

U. Becker believes that the activity of an active longitude should manifest itself systematically and uniformly (in point of time). Hence the time interval he selected, 10 revolutions of the Sun, was definitely too short for the solution of the active longitude problem. But is that really so? The term active longitude usually implies a longitudinal interval in the course of which, several years or more, the solar activity is considerably greater than in the neighboring longitudinal intervals. The point therefore is how uniform was the release of the solar activity energy and how great was that energy.

Disregarding U. Becker's postulate, we find from the charts of the Sun covering one cycle that active longitudes actually do exist on the Sun. This follows also from Fig. 2 which shows a composite chart of active solar centers for cycles 12-18. The figures denote the numbers of the cycles, and the arrows the displacements of the centers from cycle to cycle.

As already pointed out, the active centers do not reveal any tendency to deflect from cycle to cycle in the same direction. This circumstance and the tendency of the active centers to retain their longitude indicates that the Fay law is not operative in the active longitudes. Actually, in view of the large longitudinal dimensions of the areas (40°) and the large unit of time interval (cycle), the operation of the Fay law would have resulted in the displacement of the active centers in a definite direction. But inasmuch as this does not happen, we are probably dealing here with a rigid rotation, in accordance with the conclusions reached by Losh [4] and Waldmeier.

It is interesting to point out that U. Becker [3], having examined the problem of active centers, came to the conclusion that the formations in these centers rotate at a speed per revolution 2-3 degrees greater than the ordinary spots. If that were the case, these formations rotating within our time interval unit should have been displaced at least 280-290° toward the east even within a single cycle. But we see that the deflections both to the east and west are considerably smaller, and they resemble oscillations. Unfortunately, with this scale of the areas it is difficult to say whether we are dealing with actual oscillations, or whether the whole thing may be explained by the errors in the scale.

To compare our results with those of U. Becker, we shall use the isoline method to compile a synoptic chart of the sun for cycle 15, that is for U. Becker's index of the number of days in

Cycle No. 15
(U. Becker's index)

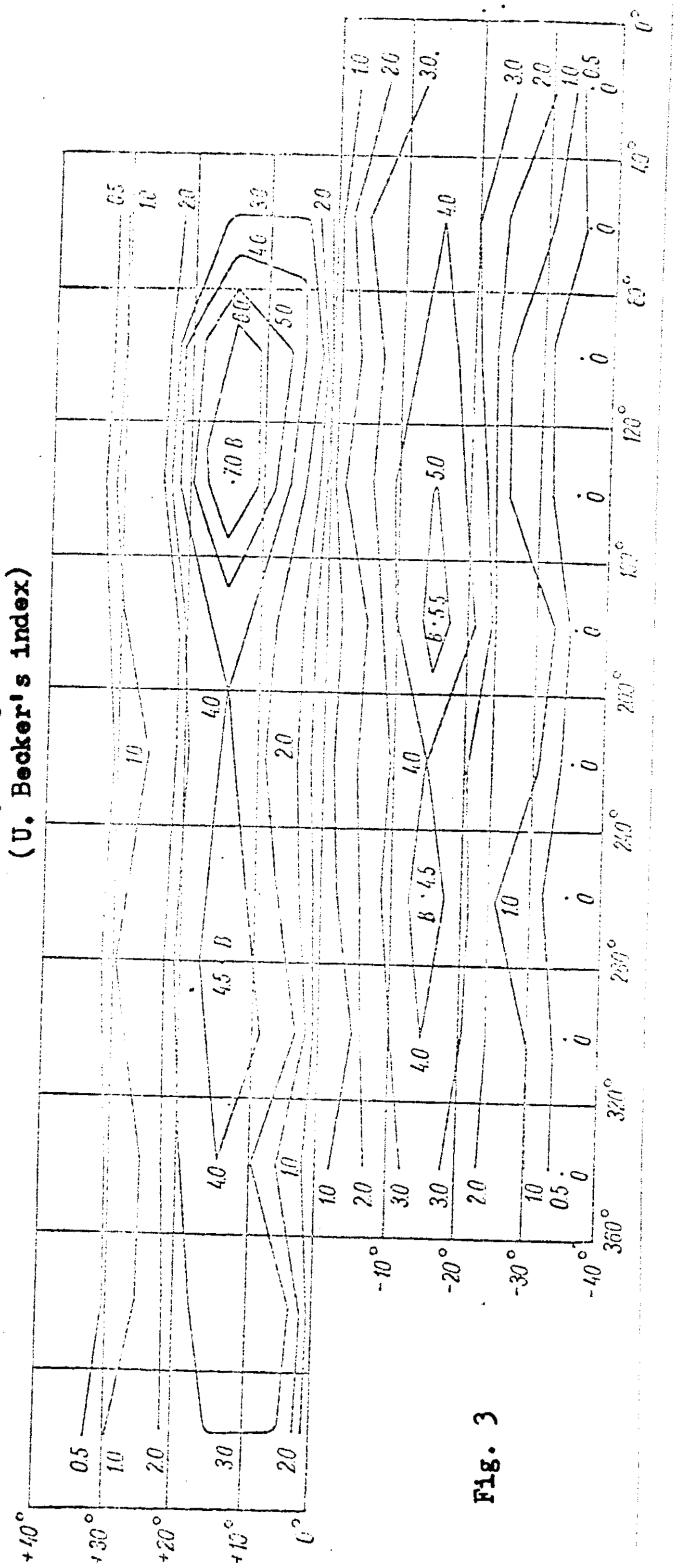


Fig. 3

which the group of spots was seen. With a longitudinal scale of 20° used by U. Becker, the picture becomes so confused that it is absolutely impossible to recognize the active centers in it. The longitudinal disjunction appears with a change to a 40° interval, but it is less clear than $\sum S_i$ (see Fig. 3). It is interesting to note that the active longitudes do not always coincide with the ones obtained from the $\sum S_i$ maps. Such a disparity could best be explained by the fact that we deal with indexes characterizing different types of sunspot groups.

Let us see which of the groups of sunspots determine the active longitudes on the Sun recognized by the synoptic charts in connection with $\sum S_i$. We will therefore compile a chart of cycle 15 for the recurrent groups (See Fig. 4). It is found that the recurrent groups produce a still more clearly defined longitudinal

Cycle No. 15 (Recurrent groups)

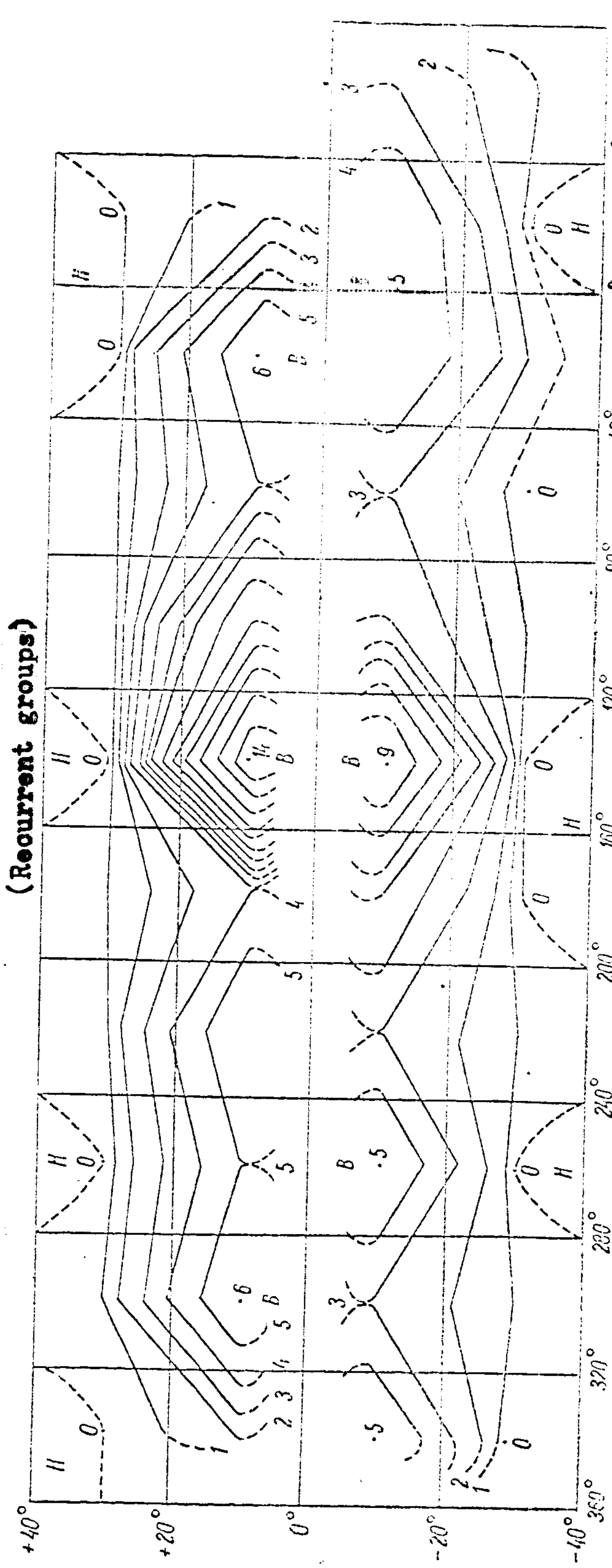
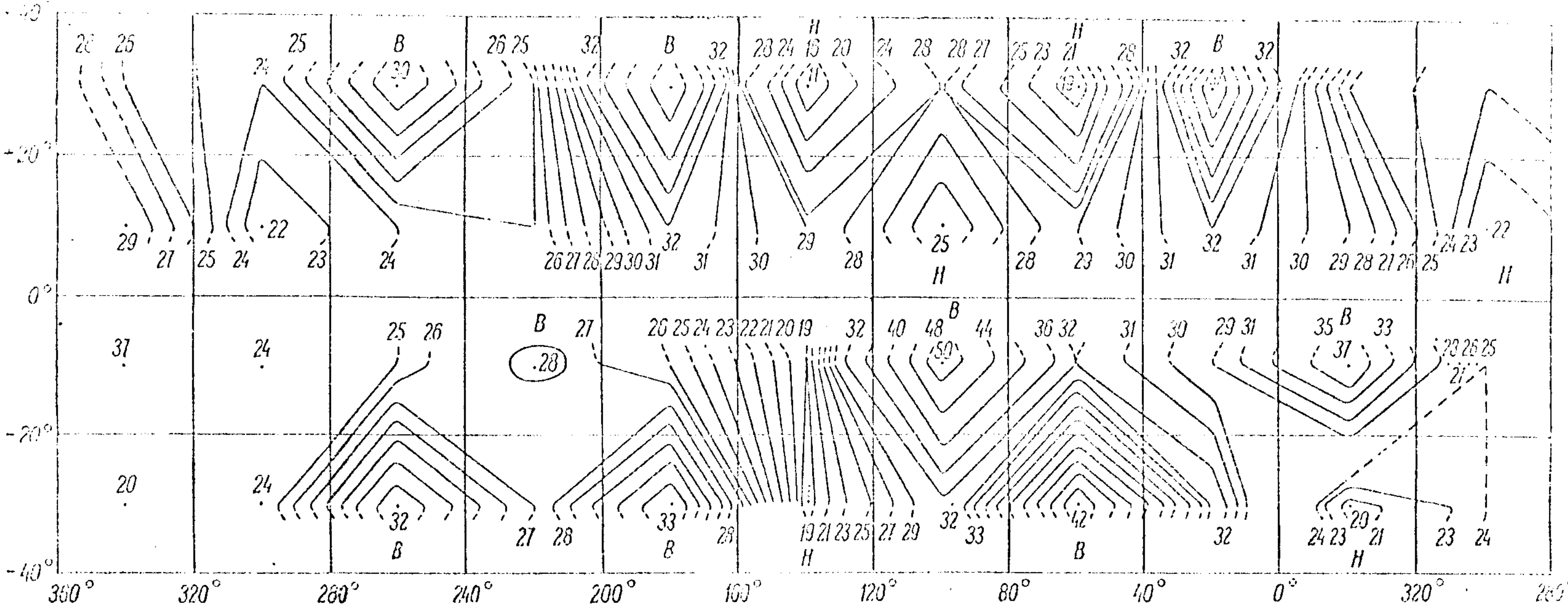


Fig. 4

Cycle No. 12



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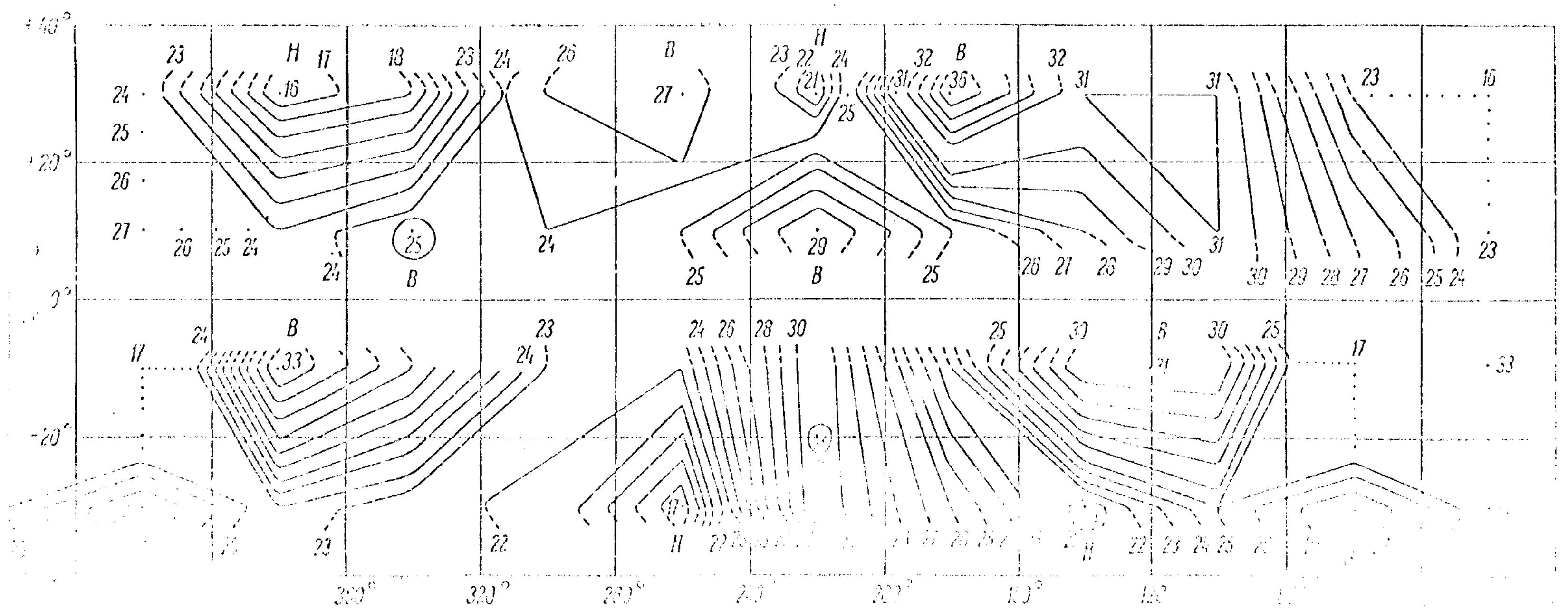

Fig. 5

dissection than all the groups put together. A similar examination of the non-recurrent groups shows that their longitudinal gradients are considerably smaller than those of the recurrent groups. Earlier [5] it was shown that there was practically no connection between the maximum area and time of the existence of recurrent groups of sunspots. It is obvious that U. Becker's index characterizes primarily the non-recurrent groups.

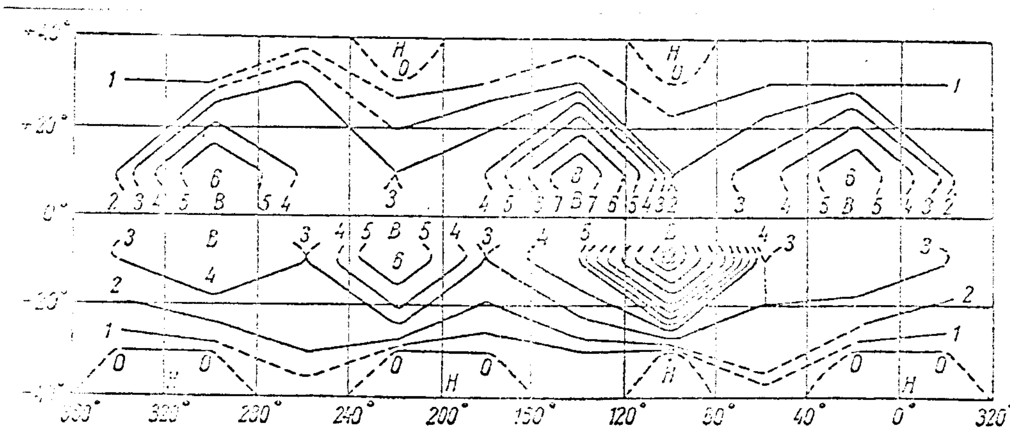

Fig. 6.

As we have already pointed out, the ΣS_i field is, strictly speaking, a discreet one. We have therefore used the isoline method to compile a synoptic chart of the sun for the probability of the values defined by this index: $S_i > 500$, $100 < S_i \leqslant 500$ and $2 < S_i \leqslant 100$. Here it was found that the maps of probability $S_i > 500$ are practically similar to the $\sum S_i$ maps. An example of such a map compiled for cycle 16 is shown in Fig. 6. We have thus reached the conclusion, by an entirely different method, that the active longitudes are determined primarily by recurrent groups, inasmuch as such groups are characterized precisely by such areas.

So far we have used ΣS_i as the index of solar activity characterizing the magnitude of the spot-formation process in a given area. We will now take a look at another index which we shall hereafter call the decay function. It is defined by the following formula

$$Q_i = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{dS_j}{dt} \right)_{\text{decay}}.$$

Here S_j denotes the daily value of the spot area, t -- the time expressed in days, and n -- the number of spot groups per area; all the S_j values refer to the time of the area reduction after the group has reached its maximum area. We should point out that we have discussed the recurrent groups not as individual manifestations but for the entire period of their existence. Inasmuch as the peripheries of the areas are characterized by all sorts of errors, we used only the data in the range of longitudes $\pm 70^{\circ}$ from the central meridian of the sun.

It is natural to believe that the resorption function is determined by the viscosity of the solar convective zone, and in this sense we may speak of the existence of a continuous field of the resorption function. We will compile synoptic charts of the sun for cycle $Q_i(\varphi, \lambda, t)$ and compare them with the corresponding ΣS_i charts. Such charts compiled for cycles 12 and 16 are shown in Fig. 5. It is interesting to point out that the southern hemisphere of the sun was more active in the first of these cycles, and the northern in the second.

An examination of the solar synoptic charts in connection with the resorption function justifies the following conclusions.

1. The active centers of the resorption function appear both in the low and high latitudes. It should be recalled that the index ΣS_i applies to the active centers which are usually located in the lower latitudes. But in the case of Q_i, the picture is considerably more complicated than the ΣS_i function.

2. There is no definite pattern in the coincidence or non-coincidence of the active centers ΣS_i and Q_i. This may indicate that the decay and

outburst characterize processes occurring at different depths.

3. The active centers of the decay function do not last as long as was observed in the case of function $\sum S_i$.

It would be interesting to draw an analogy between a curve denoting the development of an area of an individual group, and a curve representing the development of a cycle according to some solar activity index, as for example, the Stewart-Panovskiy form [6], even though there is actually an inverse dependence between the capacity and the time of development of an individual group and cycle. A comparison of the $\sum S_i$ and Q_i maps shows that we are dealing with two independent processes as it were. The first of them is conditioned by the internal layers of the Sun where the sunspots originate, and the second by the surface layers which may either destroy the group or retain it for a long time. It is possible that the

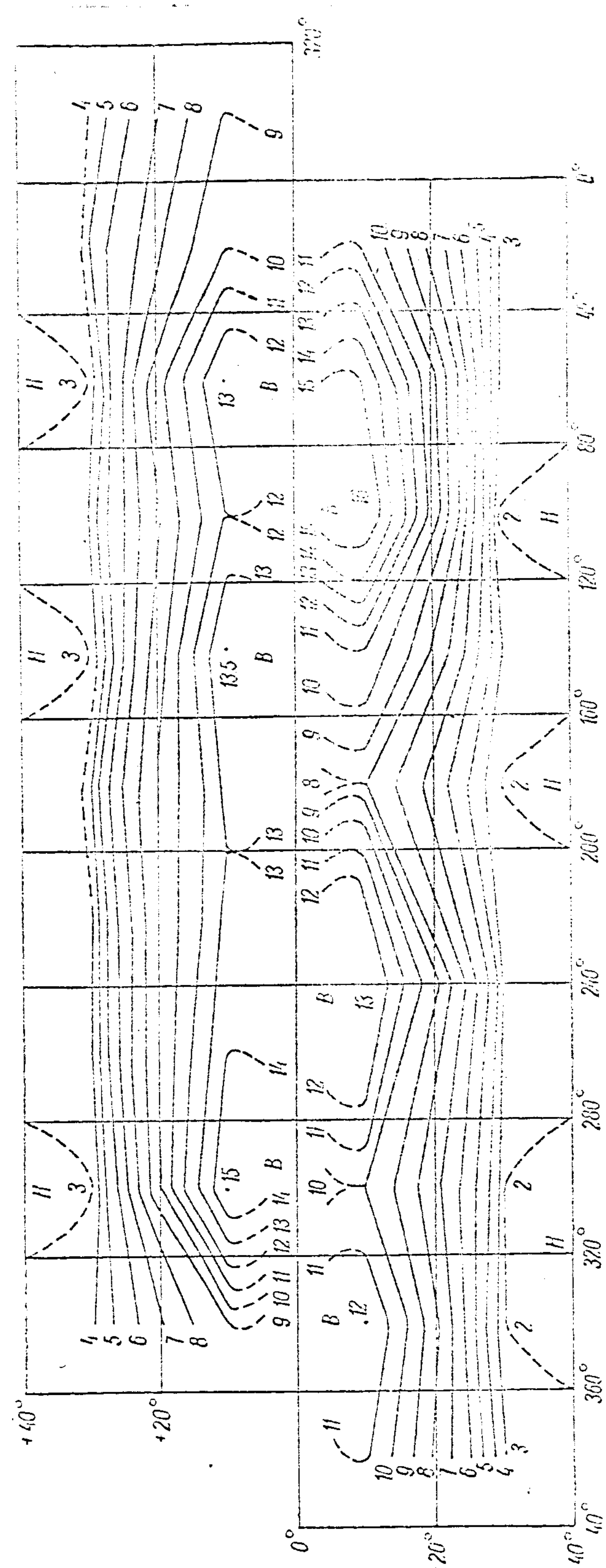

Fig. 7

cyclic curve can also be expressed by only two independent functions: outburst and decay. In this sense, the attempt of certain authors, as [7] for example, to represent it as a single-parameter function is hardly justifiable.

Having discussed the indexes of the solar activity characterizing the processes in the photosphere, it is only natural to take a look at one more index applying to the same layer of the solar atmosphere, and that is the magnetic fields of the sunspots. This index, as already pointed out, is the only indicator of a continuous field. Actually, we may be dealing with two indexes connected with the magnetic field intensities of the spots. These are 1) the total magnetic field intensity of the spots in a given area $\sum H_i$ and 2) the average magnetic intensity of a group within an area $\bar{H}_i = \frac{\sum H_i}{n}$, where n indicates the number of groups in a given area. The first of them appears to indicate the magnetic energy released in the

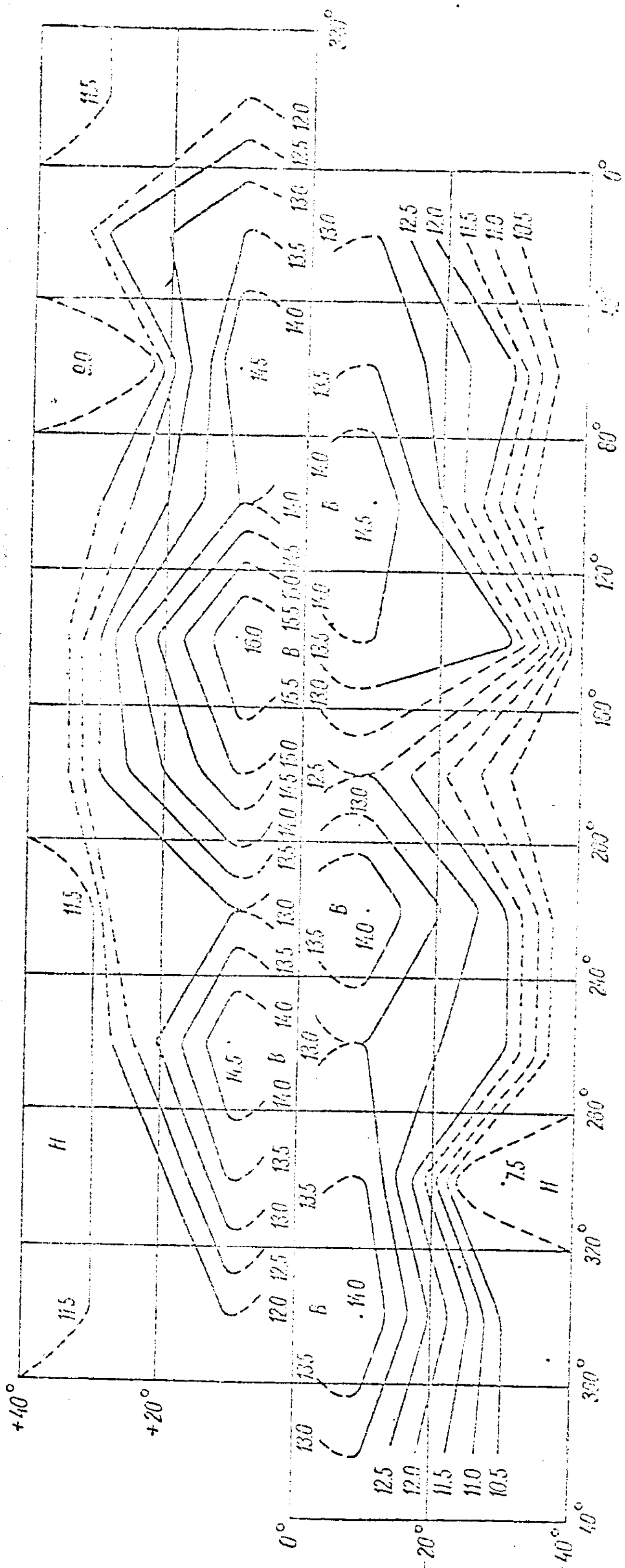

Fig. 8

course of the cycle, and in this sense it is similar to $\sum S_i$; the second characterizes the average magnetic field intensity per cycle in each area. We should point out that both indexes may be obtained only from the maximum value of the magnetic field intensity during a single passage of a group of spots, inasmuch as a fairly long series of observations have been made of only that magnitude. It should be pointed out also that in using the data on the magnetic fields of the spots we inevitably run into the problem of material selection, let alone the other shortcomings of the given index. We therefore took also the index $\overline{H}_i$, in addition to $\sum H_i$, in the effort to avoid that selection at least to some extent. Curiously enough, we obtained practically the same result in the longitudinal distribution for both indexes.

We compiled the $\sum H_i$ and $\overline{H}_i$ synoptic charts of the sun for the 16th cycle. An examination of the compiled charts (see Fig. 7 and 8) justifies the following conclusions.

1. The active longitude represented by indexes $\sum H_i$ and $\overline{H}_i$ practically coincide with those of index $\sum S_i$. This again confirms our conclusion to the effect that the recurrent groups are the basic determining population of the active longitudes inasmuch as such groups are usually characterized by large magnetic fields.

2. In point of longitude, the gradients $\sum H_i$ and $\overline{H}_i$ are considerably smaller than similar $\sum S_i$ gradients. Consequently, these indexes are much less convenient that $\sum S_i$ for the recognition of the active centers.

3. In point of latitude, the $\sum H_i$ gradient are, on the other hand, very large. It is possible that they are partially connected with the selection of material and partially with the operation of the Sperer law. Unfortunately, in this case it is practically impossible to separate these

two factors. As for the $\overline{H}_i$ index, we have here considerably smaller latitudinal gradients which are practically comparable to its longitudinal gradients.

Our conclusions show that it does not pay to make a special investigation into the distribution of $\sum H_i$ and $\overline{H}_i$ in other cycles, as we will actually get the same results to which we had been led earlier by an examination of the solar synoptic charts for $\sum S_i$.

Finally, we shall also discuss the problem of the peculiarities of the recurrent groups inhabiting the active longitudes. For that purpose we shall compare such groups in the active and passive longitudes (that is, such groups where $\sum S_i$ had a minimum value in comparison with the neighboring longitudinal sections), as in cycle 16, for example. And here we find that the active longitudes usually contain more recurrent groups with a maximum area exceeding 500 m. p. a. (maximum permissible area [?]) than the passive longitudes. The maximum magnetic intensity of such groups is on the average higher in the active longitudes, and their life is therefore also longer, as we have shown earlier.

On the average, we obtained the following values for active and passive longitudes:

Number of groups with $S_{max.} > 500$ m. p. a....	6	3
H (in gauss)	2900	2700
T (in revolutions)..........................	2.5	2.1

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